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THE PALAEOGEOGRAPHIC EVOLUTION OF THE NETHERLANDS DURING THE QUATERNARY

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ABSTRACT

An outline of the palaeogeographic evolution of the quaternary sedimentary basin of The Netherlands is given, based on a discussion of 12 maps, figured in the enclosure. In the second part of the paper a documentation of the sources used is given.

INTRODUCTION AND ACKNOWLEDGEMENTS

This paper consists of two parts. The first is an overall review of the Quaternary geologic history and palaeogeographic evolution of the sedimentary basin of The Netherlands. Originally this part was written for a lecture in French, delivered to a general public at the Institut Néerlandais at Paris in December 1972. In agreement with its general character, no particular reference to existing literature has been given in this part of the paper. Instead the reader may be referred to P a n n e k o e k (1956) and d e J o n g (1967), who have given an excellent review of existing literature.

The second part gives as short as possible an enumeration of the sources used in the construction of the palaeogeographic maps, the timescale and the climatic curve. Furthermore a number of unpublished considerations have been dealt with in some detail.

Pollen-analytical data, obtained during the last twenty years have often been a key to appropriate dating of the observed geologic phenomena, which is essential in making palaeogeographic reconstructions. As far as unpublished material is concerned, this is filed in the Palaeobotanical Department of the Geological Survey of The Netherlands.

The author is indebted to the Director of the Geological Survey of The Netherlands for permission to publish these results and for support in publishing the maps. Furthermore he is very much obliged to his colleagues and other co-workers of the Geological Survey for the many observations and informations they kindly communicated to him. Among them Mr. J.G. Zandstra should especially be mentioned for his most important advises. Dr. S. Jelgersma kindly provided an unpublished manuscript map, which has been used as basis for the pattern of glacial basins in map 8. Dr. W. Roeleveld kindly permitted the use of manuscript data from the Groningen area in the construction of map 12.

The execution of the maps has been skilfully carried out at the Cartographic Department of the Geological Survey, by Mr. M. Dansen and his collaborators A. Walkeuter and R. Metten.

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GENERAL PART

The Netherlands deserve their name, both from a geographical and a geological point of view. The geographical aspect is evident. Only in a periferal area in the extreme southeast which forms a transitional area towards the hills and mountains of Central Europe, altitudes exceeding a hundred metres occur. Elsewhere most of the country shows a flat morphology with a groundsurface of some metres above or below sea level. However there are also exceptions, namely in the coastal dune area, where heights of 60 m have been measured occasionally and in the Central Netherlands, where hills may attain a height of a hundred metres.

In this paper an outline will be presented on the evolution of the landscape and on its geologic history. A particular feature is, that in general the sediments which yield the necessary information for palaeogeographic reconstructions occur below the present surface. Consequently, most information has been acquired from temporary artificial exposures and particularly from borings. Therefore, laboratory techniques, applicable to examination of small samples have provided much of the data used in the interpretations. Among these techniques heavy-mineral and gravel analysis, foraminiferal research and pollen analysis are the most outstanding.

Down to a depth of some tenths to several hundreds of metres the deposits are of Quaternary age, not older than about 2.5 million years. These deposits were for the greater part laid down in a coastal area. This means, that they were deposited either in a shallow sea, not deeper than a few

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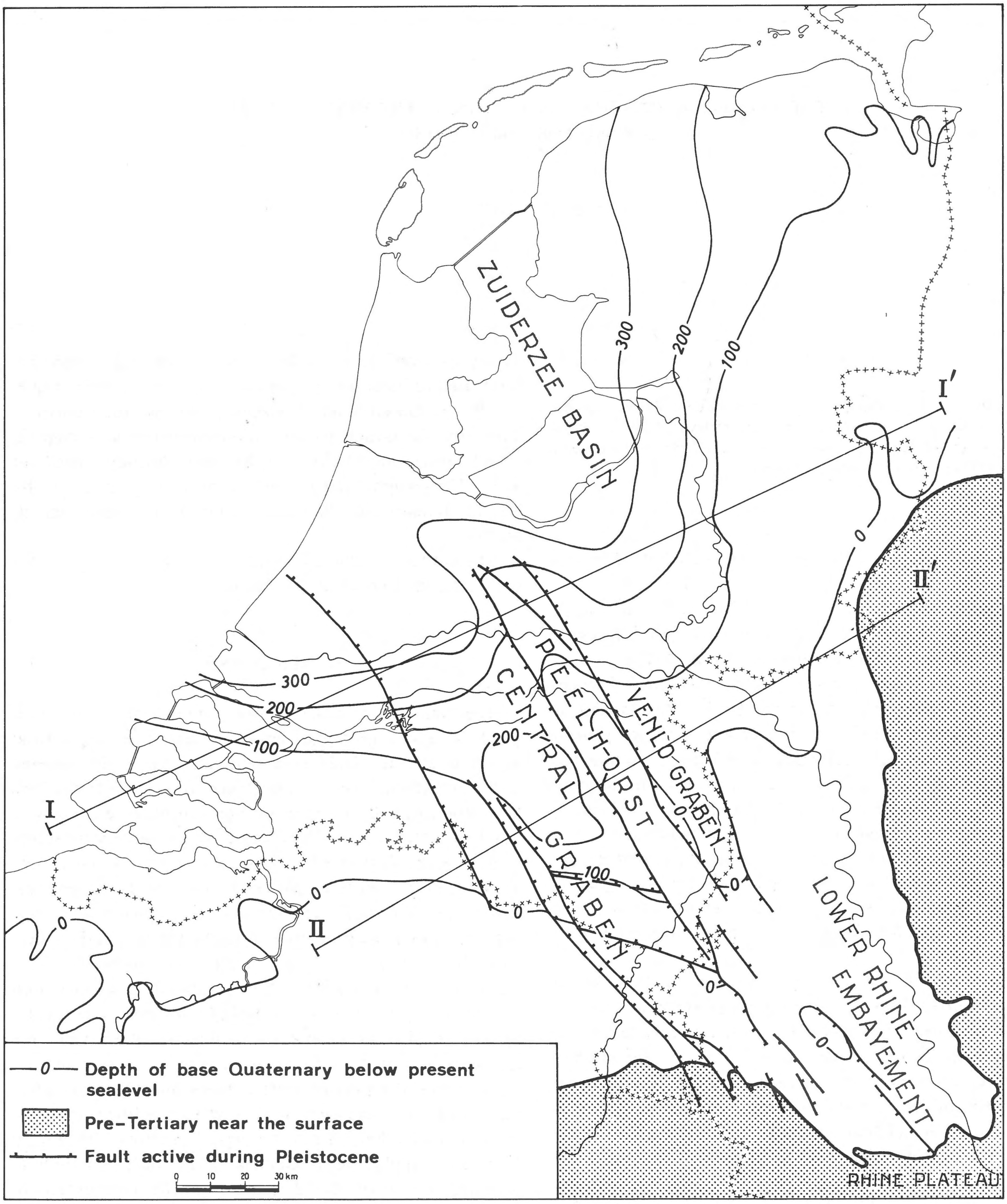

Fig. 1
Depth contours of base Quaternary, faults and main tectonic units. Contours below 300 m have been omitted.

tenths of metres, or in coastal swamps, lagoons and lower river courses. In other words, these beds were deposited slightly below or above sea level. At present, however, they are often found at considerable depth below sea level, even as much as 400 to 600 metres (fig. 1). It indicates, that since the beginning of Quaternary times downwarping has taken place to an amount approximately equal to the depth at which the basal Quaternary beds are found at present. It may

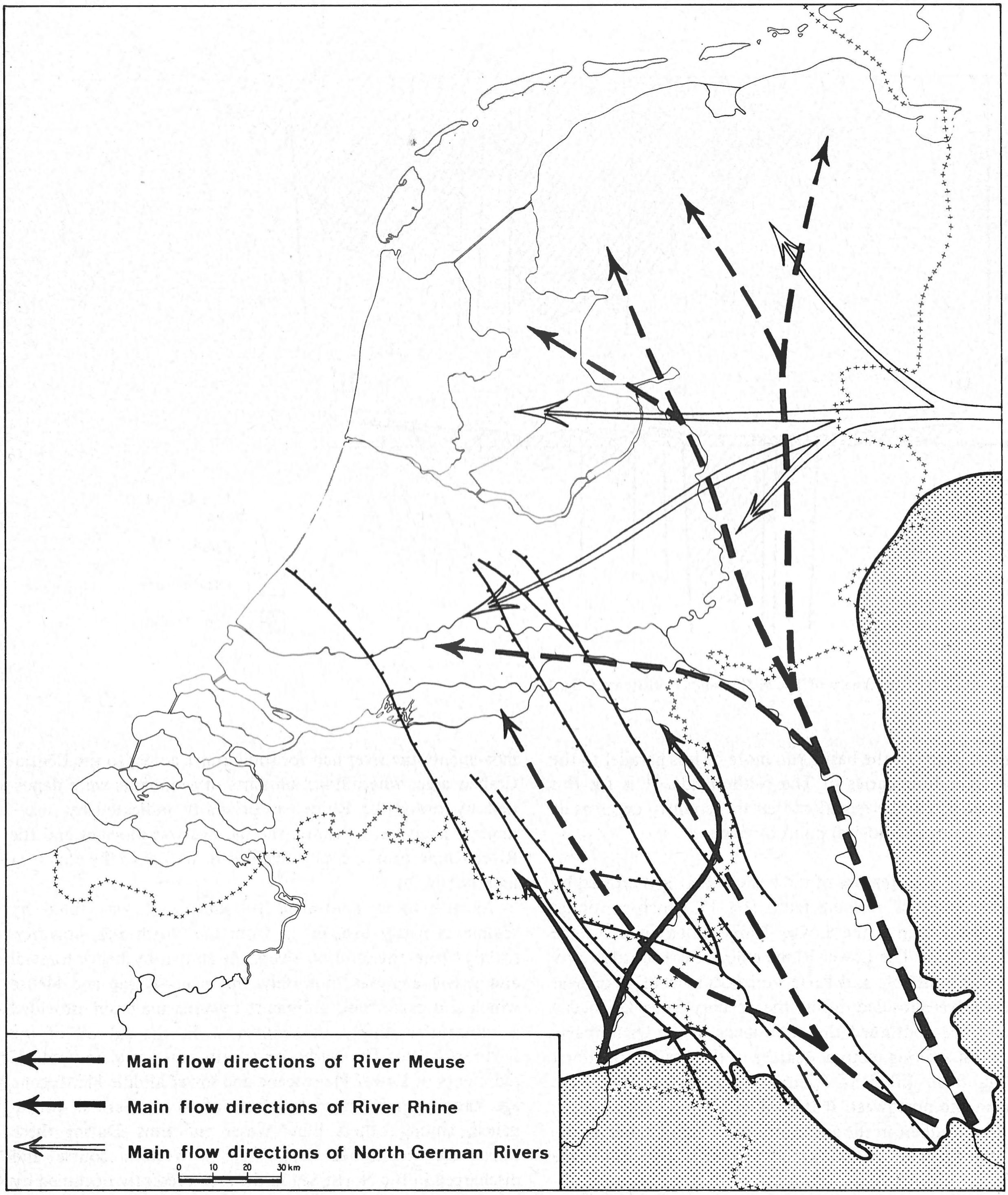

Fig. 2
Pattern of main flow directions of great rivers during the Quaternary.

be concluded, that the area has been an active sedimentary basin since the Quaternary. Of course, many sedimentary basins are known from the geological past. However, those that are still active are scarce, and among them the basin of The Netherlands, a densely populated area, has probably been investigated in closest detail to date.

It is interesting to note that the depth contours of the base of the Quaternary, especially that of 0 metres indicating

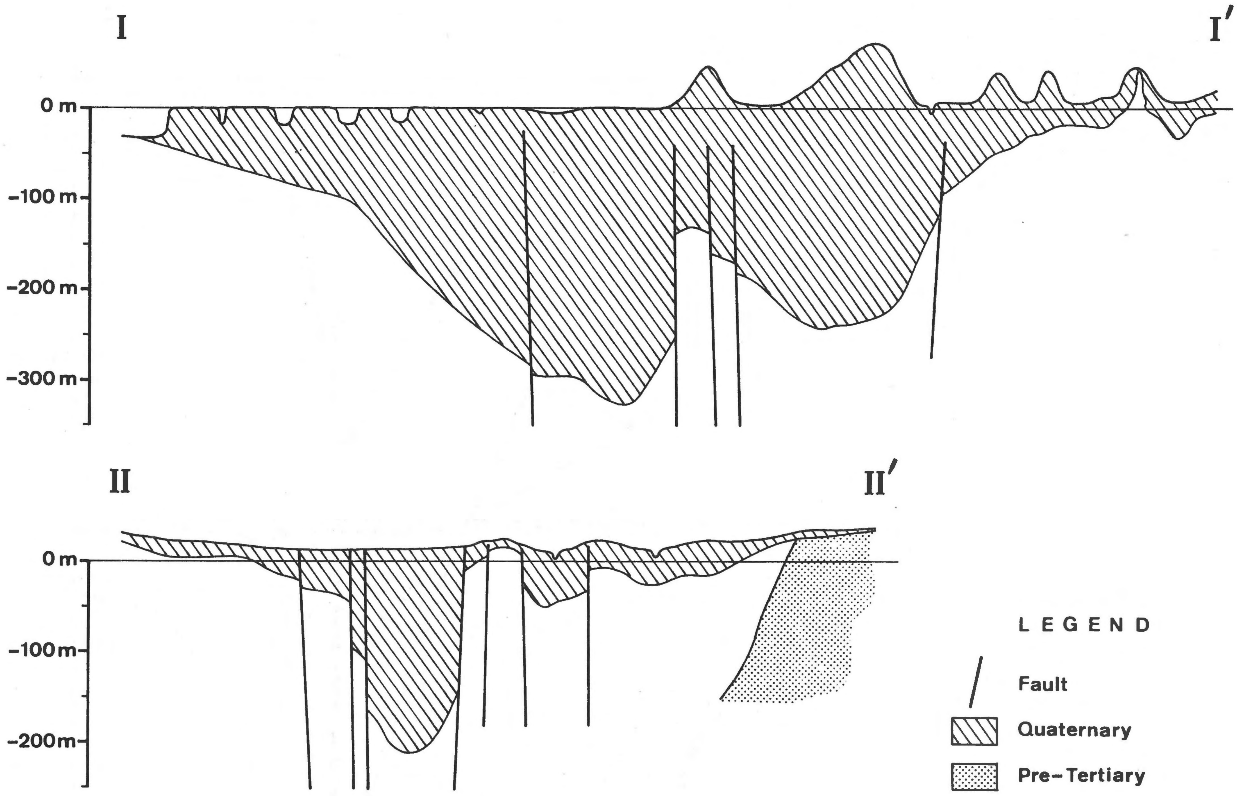

Fig. 3
Two sections of the Quaternary of The Netherlands (location see fig. 1).

the general shape of the basin, run more or less parallel to the present state boundaries of The Netherlands. It is for this reason that it may be remarked that this country deserves its name also from a geological point of view.

A characteristic feature of the basin is that it is crossed by a system of SE-NW running faults (fig. 1), which continues towards the SE into the Lower Rhine embayment to the vicinity of Bonn. The Lower Rhine embayment, bordered by areas where Mesozoic and Palaeozoic rocks occur at or near the surface has subsided during the Tertiary, since Oligocene times and has continued this subsidence in the Quaternary.

The most striking tectonic feature of the basin is the horst extending from Erkelenz (Germany) in the southeast to Utrecht in the northwest. It is flanked by two Graben areas, the Central Graben in the south and the Venlo Graben in the north (fig. 1). The latter extends towards the Zuiderzee Basin.

The two sections (fig. 3) present an impression of the relative importance of these structural features during the Quaternary. As will be shown later in more detail, differential movements along these structures had a strong influence on the distribution pattern of the Quaternary sediments. Tectonic movements have in particular affected the course of the River Rhine, downstream the place where this river leaves the Rhine Slate Plateau near Bonn. Due to such tectonic movements the river had for some times access to the Central Graben area, where huge amounts of sediments were deposited by the River Rhine, as presently indicated by heavy mineral analyses; at times, the passage was blocked and the River Rhine took a course due north, similar to the course at present (fig. 2).

As the basin continued to subside it was filled by sediments partly brought in from the North Sea, however, mainly from the land by rivers. As shown by heavy-mineral and gravel analyses, not only the rivers Rhine and Meuse which still carry their sediments towards the basin, provided a substantial supply of sediments. In the subsoil of the northern half of The Netherlands very substantial amounts of sediments of Lower Pleistocene and lower Middle Pleistocene age have been provided by rivers of North German provenance, among others Elbe, Weser and Ems. During these times the mentioned rivers had a western course and discharged in the North Sea in the area presently occupied by the northern Netherlands (fig. 2).

Variations in intensity of tectonic movement and changes in the river courses have been two of the factors which have determined the geologic genesis of the subsiding basin of The Netherlands during the Quaternary. A third substantial factor has been the changing climate. Although the investigation of Upper Tertiary deposits indicates the occurrence of cyclic alternation of cooler and warmer climatic episodes already during this time, it is in the Quaternary that these fluctuations attained such an intensity that during cold episodes glaciers could extend to middle latitudes of North America and Europe. The first episode of intensive cold is at present known to have occurred about 2.5 million years ago and it marks the beginning of the Quaternary epoch.

The climatic changes during the Quaternary have largely influenced vegetation. The study of fossil plant remains, found in sediments suitable for their conservation, has been particularly important for the reconstruction of the repeated climatic fluctuations during the Quaternary in the area of The Netherlands. Especially pollen analysis has proved to be an invaluable tool in these reconstructions. The greater part of the climatic curve, constructed and shown in the enclosure, is based on above mentioned studies effectuated mainly during the last twenty years.

The vegetational variations have been considerable. During cold phases (glacials) forest was replaced by open toundra-like vegetations, similar to those found in the northernmost parts of Europe and Siberia and in the Alpine zones above the timberline. Ecologic conditions were: cold climate, at times dry, perennially frozen soil (permafrost), abundance of light, prevalence of mechanical erosion, minor soil formation.

On the other hand forest prevailed during the warmer episodes (interglacials). The forest was of the Middle European type, which thrives under the present climatic conditions found in The Netherlands. During interglacials ecologic conditions were: humid, temperate climate, much shadow, minor mechanical erosion, much soil formation.

The pollen-analytical data available to date, indicate a rather complicated alternation of warmer and colder episodes, as is shown by the graph figured on the enclosure. However, probably the true picture of events may appear to have been even more complicated. There are strong indications that particularly in the Middle Pleistocene more warm-temperate episodes (interglacials) have existed than recognized to date. Moreover, from the glacial phases in the uppermost part of the Quaternary some slightly warmer episodes (interstadials) are known. It is highly probable that in older parts of the Quaternary where present knowledge is naturally less complete, many similar interstadials may eventually be recognized.

In addition to the palaeoclimatic data an insight is required into the true or absolute age of the deposits. In this area some methods are suitable to acquire such data. As to the last 50.000 years a vast number of radiocarbon datings is available. For older deposits palaeomagnetic records provide information on the age of deposits older than 700.000 years, when periods occured during which the polarity of the earth' magnetic field was reversed as compared to the present one. In some volcanic rocks both the palaeomagnetic polarity and the radiometric absolute age have been measured, and it has resulted in a standard palaeomagnetic time-scale. When a series of sediments cannot be dated by means of radiometric methods, changes in palaeomagnetic polarity may be compared with the standard palaeomagnetic time-scale. By this procedure absolute datings may be obtained also in areas lacking volcanic rocks, like The Netherlands.

Summarizing, the geologic study of the Quaternary basin of The Netherlands has resulted in the recognition of a number of sedimentary units, which are related to certain climatic variations. Consequently their place in the time-scale may be known. Different lithologic units occurring in various parts of the area, may be shown to be of similar age, among others those consisting of marine and fluviatile sediments. The study of the lateral relations of different sedimentary units deposited during a certain time-interval has resulted in the construction of a series of palaeogeographic maps shown on the enclosure.

ENCLOSURE MAP 1 – REUVERIAN (UPPER PLIOCENE)

Since Middle Tertiary time and until the end of the Tertiary a considerable part of The Netherlands was covered by sea. During the uppermost part of the Tertiary the configuration of the coastline was as shown on the map, which will be called concave; its shape is evidently determined by the tectonically active area of the Central Graben and Lower Rhine embayment in the southeast.

The River Rhine had its course towards the northwest and was building a delta in the Central Graben area. In the northeast, deltabuilding by North German rivers took place. Notwithstanding the great thicknesses of these fluvial sediments deposited during Upper Tertiary times, shift in coastline was very limited. Therefore, it may be concluded that the rate of subsidence and the rate of fluviatile sediment accumulation were in equilibrium.

ENCLOSURE MAP 2 – MIDDLE PART OF THE TIGLIAN (TC3)

The configuration shown on map 1 persisted during Upper Tertiary times for several million years and remained with little modification in the beginning of the Lower Quaternary.

In the middle part of the Tiglian interglacial the River Meuse was a tributary of the River Rhine, and it had a northeasterly course from the Ardenne region. The sedimentation area of the River Rhine had extended towards the northwest in the Central and Venlo Grabens. In the northeast the delta of the German rivers had become slightly larger than in Tertiary times. Though a slight shift towards the north and west of the coastline may be observed, its general shape and position was similar to that during Upper Tertiary times.

ENCLOSURE MAP 3 – UPPER PART OF TIGLIAN (TC5)

This map, representing the geography only some 200.000 years later, shows a completely different distribution pattern of land and sea. The coastline had shifted such a distance to the west that the sea did not occupy the present territory of The Netherlands anymore. The deltas of the Rhine and the North German rivers had largely extended westward and had merged into one enormous delta protruding into the North Sea. The concave shape of the coastline had changed within a relatively short time into a convex one, reminiscent of the shape of the present-day coastline of this country. The change in equilibrium was rather the result of a large increase in affluence of fluvial sediment than of decrease in subsidence. Actually the thickness of the fluviatile beds dating from this relatively short period is considerable, especially in the northwestern part of the area.

After the Tiglian a long phase of cold followed, i.e. the Eburonian glacial. During this time, about 1.5 million years ago, large ice-sheets covered North America (Nebraskan inland-ice). Large amounts of ocean water remained frozen as inland-ice, resulting in a considerable drop in sea-level, which is similar to what happened during following phases of large glacier building. Parts varying in extent of the North Sea, a shallow shelf sea, became land during these cold phases. However, as pertinent geological information from below the present North Sea floor is still lacking, it is impossible to reconstruct the configuration of the coastline during the Eburonian and later glacial episodes.

Therefore, most of the palaeogeographic reconstructions in this paper are related to interglacial phases, from which the configuration of the coastline is known. Only for the last two glacials of the Quaternary (Saalian and Weichselian) maps have been constructed.

ENCLOSURE MAP 4 – WAALIAN INTERGLACIAL

During this stage, which ended some 700.000 years after the close of the Tiglian, the configuration of the coastline was similar to the late Tiglian one. A new equilibrium between subsidence and sedimentation had been established. In contrast to what had been the case during the Tiglian, the River Rhine had a course roughly comparable to its present one. The River Meuse and other tributaries of southern provenance transported their sediments towards the Central Graben area, which was abandoned by the River Rhine. In this part of the delta fine-grained deposits were laid down. In the northern part of the delta sediments from the North German rivers were piled up in great thicknesses. These sediments consisted mainly of gravelly coarse sands.

At least two interglacials are known from the lower part of the Cromerian complex, dated between about 800.000 and more than 400.000 years ago. Unfortunately no information is available to assist in reconstructing the coastline during that time. It may have been similar to that during the Waalian. During the lower part of the "Cromerian complex" the course of the River Rhine had changed again. Once more it was flowing towards the northwest, through the Central and Venlo Grabens; the River Meuse was a tributary in the SE part of the country with a northwestern course. Sedimentation by North German rivers continued during this lower part of the "Cromerian complex" in the Northern Netherlands. No palaeogeographic reconstruction has been made for the lower "Cromerian".

ENCLOSURE MAP 5 – UPPER PART OF CROMERIAN COMPLEX

This map shows the situation soon after approximately 400.000 years ago, during the upper part of the "Cromerian complex". The convex coastline was similar to the present one with regard to shape and position. The Rivers Rhine and Meuse were forming a huge delta, covering the greater part of The Netherlands. From this time onward the River Rhine has followed a course similar to its present northerly course in the Lower Rhine district of Germany. Also from this time onward the North German rivers flowed outside the area under discussion, with occasional exceptions of the River Ems.

It would be highly interesting if a reconstruction of the palaeogeography during the Elsterian glacial could be made. There are pertinent indications from deposits, found in the subsoil of the Northern Netherlands, that inland-ice had reached this part of the country or was very near to it. However, the actual genesis of these deposits, known as "potklei" (i.e. pottery clay), is not well understood. Two problems remain to be solved in this connection. The first is the origin of the deep and rather narrow basins or gullies in which this "potklei" apparently has been deposited. The other is the virtual absence of till related to the inland-ice.

ENCLOSURE MAP 6 – HOLSTEINIAN INTERGLACIAL

More is known about the situation during the Holsteinian interglacial, the exact absolute age of which can only be roughly estimated at 200.000 years. During this time the coastline ran more or less east-west parallel to the present northern shoreline of the country. The River Rhine was flowing from the Lower Rhine district, where its course was similar to the present one, to the northwest where an alluvial fan of moderate dimensions was built. Fluvial sediments were mostly finegrained. The River Meuse had a course slightly more to the west as compared to its present one and subsequently joined the River Rhine.

The deposits of all the phases discussed so far, may be found in the subsoil of the country, generally covered by younger deposits which are a few to some tenths of metres thick. During their deposition there was little morphological relief. The present landscape has been modelled afterwards.

ENCLOSURE MAPS 7 AND 8 – SAALIAN GLACIAL

During the Saalian glacial, probably some 150.000 years ago, a large sheet of inland-ice covered Northern Europe. This inland-ice also reached The Netherlands and covered about half of the territory (map 7). This event had a profound influence on both the sedimentation pattern and the morphology of the landscape.

The rivers Rhine and Meuse were forced in a westerly course, parallel to the southern limit of the inland-ice. In front of the inland-ice coarse sand and gravel were deposited in fanlike plains by streams running off the glacier front.

South of the glaciated area, toundralike conditions existed. The subsoil was perennially frozen (permafrost). Sedimentation of deposits linked with a permafrost environment, especially that of eolian loam and sand, prevailed in the Central Graben area and its surroundings. In the extreme southeast very fine, eolian deposits called loess, were sedimented.

ENCLOSURE MAP 8

The inland-ice in its marginal areas modelled strongly the sediments in the subsoil. A number of basins was shaped and at the same time the flanks and fronts of these basins were pushed in the shape of hills, the internal structure of which shows many folds and overthrusts, which are witnesses of the tectonic forces exerted by the glacier.

During a certain stage the marginal area of the inland-ice in this country was lobate as revealed by the present pattern of the icepushed ridges. The individual glacier-tongues were able to produce the appreciable forces necessary to deform a perennially frozen soil into ice-pushed ridges. This must have been a situation, which is not readily encountered at the margin of a lowland ice-cap. The author assumes that the phenomenon of glacier surge, at present known from many arctic glaciers, acted also during those times. Preceding a surge, part of a glacier builds an unusual thickness upstream, until a situation of instability is reached. During the following surge large masses are transported towards the glacier snout. Velocities of a surge are very high, much higher than those possible in normal glacier flow. Such high velocities may have been responsible for the considerable forces, which the Saalian inland-ice produced in order to build the ice-pushed ridges of the Central Netherlands.

The ice-pushed ridge of the Eastern Veluwe is more than one hundred metres high. Glacial erratics found on top of the hills indicate, that ice has covered this ridge after its formation. The glacial basin east of this ridge, near Deventer, is at its base about 125 metres below present sea-level. Therefore the thickness of the inland-ice was 250 metres or more.

Further to the north two zones of low ice-pushed ridges have been found; the ridges of the southernmost zone are mostly overlain by younger sediments. The northern zone of ridges occurs along the line Steenwijk – Gaasterland – Texel.

In contrast to the ridges in the central part of The Netherlands, which consist of sediments older than Saalian, the northern ridges contain a considerable amount of till.

North of the Steenwijk – Texel line a till area covering most of the northernmost part of the country is present. Partly the till is at or near the surface, as for example in the province of Drenthe, where the till area forms a plateaulike feature, partly it is overlain by younger sediments, like in the NW part of the province of Friesland and below the Wadden Sea. Basins are generally absent in this area, which was during the time it was covered by the inland-ice rather an area of deposition (of till) than of erosion, contrary to the central part of The Netherlands.

When the Saalian inland-ice melted down, an accidented landscape was left in the Central Netherlands. There were lakes in the former glacier basins which were filled by lake clay, which partly shows the presence of typical warve structures (this is annual layering in lake sediments in front of glaciers). At the same time, erosion affected parts of the ice-pushed ridges. The result was, that at the close of the Saalian some of the differences in height originally caused by the inland-ice had already been levelled.

Although the River Meuse maintained the westerly course it had attained during the maximum extent of the inland-ice, the River Rhine returned to its northerly course, flowing through the basin area of Deventer towards the Noordoostpolder where it turned to the west. Here, this river has cut a valley with its floor at about 50 metres below present sea-level.

In the northeasternmost part of the country another deeply incised valley dating from the above mentioned period has been found, i.e. the present Hunze valley, which has presumably been formed by the River Ems. The deep erosion of these valleys may be related to the very low sea-level, which was approximately two hundred metres lower than at present during the maximum extent of the Saalian inland-ice.

ENCLOSURE MAP 9 – EEMIAN INTERGLACIAL

During this warm-temperate stage, approximately 100.000 years ago, melting of the inland-ice resulted once more in a rise of sealevel. As shown in the map the North Sea could penetrate far to the east in areas of former glacier basins and deeply eroded valleys. The sediments deposited in the bays thus formed, further filled the pre-existing depressions. The marine beds are presently found under a cover of ten to about twenty metres of younger deposits. In sheltered bay areas tidal flat deposits and backswamp peat were formed. The River Rhine continued its northern course which it had at the end of the Saalian and the River Meuse probably had the same course as it has at present. In the southwest a valley system of the River Scheldt and its tributaries came into existence. Here estuarine sedimentation prevailed.

Outside the main areas of deposition some rather small

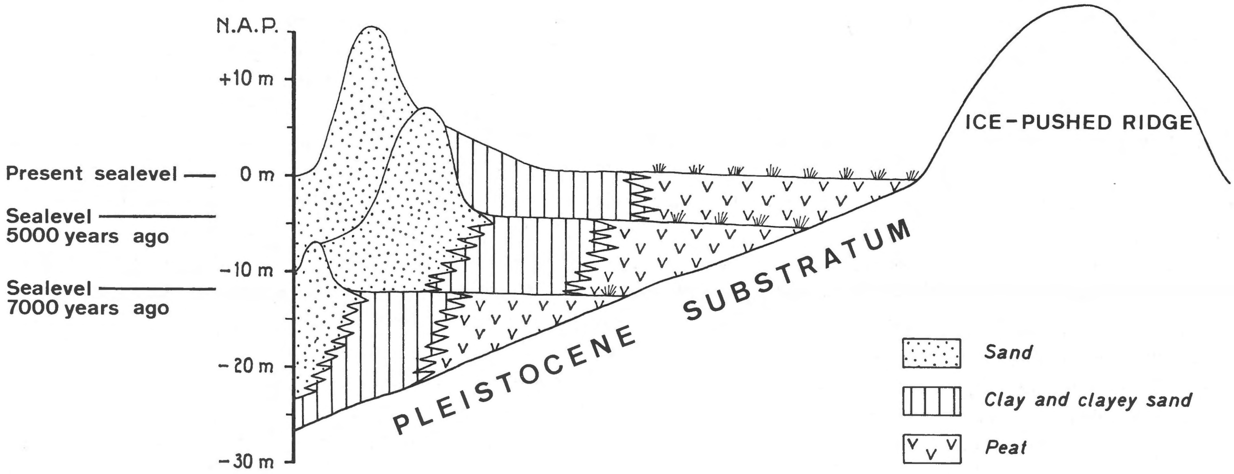

Fig. 4
Scheme of lithologic succession related to Holocene rise of sea level.

areas of peat bog formation were present. As will be discussed later, swamps and peat bogs have been formed more commonly during the Holocene. Probably a better drainage was present during the Eemian due to the greater relief.

ENCLOSURE MAP 10 – WEICHSELIAN GLACIAL

After the Eemian the story repeats itself once more. The climate became cold again, glaciers accumulated and the sea-level dropped. The forest vegetation once more gave way to open toundra and polar desert. This time the extent of in-land-ice in Northern Europe was more restricted than in the preceding glacial, and The Netherlands remained completely in the permafrost zone. During this last glacial, which lasted from about 75.000 to 10.000 years ago, huge quantities of sediments were deposited, which show relation to a permafrost environment. Particularly the regular occurrence of frost-wedges in these beds indicates the presence of permafrost conditions at that time.

Greater part of the sediments deposited under the permafrost conditions were eolian sands, which are commonly called cover-sands, as they cover the underlying morphology like a blanket. Other deposits of the permafrost environment were sedimented in valleys by melt-water, on slopes by solifluction, in lakes formed by stagnation of water on top of the impermeable permafrost. On elevated terrains erosion acted strongly. Through these phenomena the relief modelled by the Saalian inland-ice was further levelled and disappeared completely in some places.

At the end of the Weichselian glacial, about 10.500 years ago, the sea-level was still low and the greater part of the North Sea was a landsurface. The map shows that in the west as well as in the north of the country areas with little relief were present which were cut by two big shallow valleys with an east-west extension, marking the former courses of the rivers Rhine and Meuse. In the map, that part of the ancient land surface of about 10.000 years ago, which is at present below sea-level, has been indicated by its own color. This area could be flooded during the subsequent rise of sea-level and filled by sediments.

ENCLOSURE MAPS 11 AND 12 – HOLOCENE

During the most recent climatic amelioration, the Holocene, the sea-level rose again as a result of melting of inland-ice. The sea invaded once more the present North Sea area and eventually reached the present coastal area of The Netherlands.

During its rise in level there were three zones of sedimentation: a littoral sandy zone of beach ridges and dunes, a clayey zone of tidal-flats, salt-marshed and brackish lagoons and at greatest distance from the sea a zone of peat formation in a fresh water environment. These zones shifted to the east as the sea gradually flooded the formerly dry North Sea floor. In fig. 4 a scheme is given to illustrate how in relation to rise in sea-level and coastal shift the deposits of these zones could accumulate on the inclined land surface. The Holocene deposits may reach a thickness of more than 20 metres in the western coastal part of The Netherlands.

Map 11 illustrates the palaeogeographic situation at about 5.000 years B.C. when the sea flooded the coastal areas of The Netherlands again. The three zones mentioned can be traced, though part of them may only be reconstructed hypothetically, as much of the deposits of that time have been eroded off when the coastal barrier zone shifted further to the east in a later phase.

Finally map 12 illustrates one of the final stages in the evolution of the coastal barrier ridge zone at about 2.300

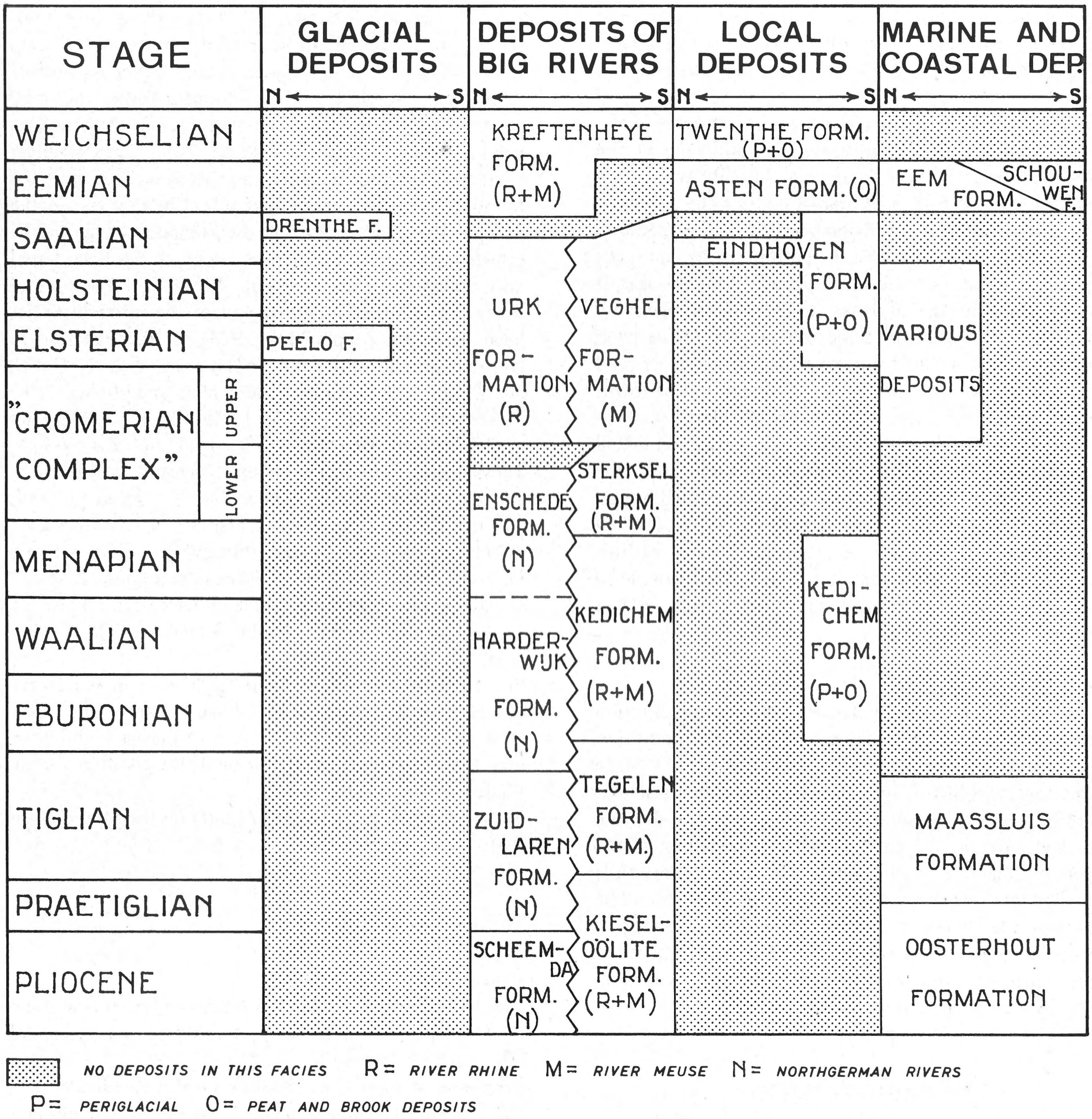

Fig. 5
Table of Pliocene and Pleistocene Formations in The Netherlands.

years B.C. The zone of beach barriers and dunes was fixed and was enlarged towards the west. Behind the barrier zone fresh water flowed in from the rivers Meuse, Rhine, Scheldt and others. The result was that in the area behind the barrier-zone the salt water was replaced by fresh water. Consequently here peat bogs developed in areas of former tidal flats and brackish lagoons. This holds particularly true for the west-central coastal area of Holland, where clay deposition was nearly absent at this time. The rivers Rhine and Meuse branched into several lower courses which crossed the coastal plain and flowed into the North Sea through estuaries.

Except for the extent of peat formation in the coastal plain areas, peat bogs were also widespread further inland. For instance, in the northeasternmost part of The Netherlands the huge highmoor of Boertange came into existence; this highmoor has once been the largest of the continent. This general peat formation during Holocene times is contrary to the situation during the Eemian. Probably poorer drainage of surface water during the Holocene as compared to the Eemian because of diminished relief may have been the main cause for this difference, rather than difference in climate between the two temperate stages.

The map shows the palaeogeographic situation at a moment when neolithic man started to intervene in the natural development of the landscape. Initially prehistoric farmers have cut the forests in order to obtain the necessary areas for agriculture and husbandry. Later, since medieval times, man has directly changed the pattern of the landscape by the construction of dikes to protect himself against floods; by the drainage of lakes in the coastal plain; by reclaiming land and changing flooded areas into fertile land; by levelling, which includes dumping huge amounts of sand on soft, peaty soils to allow for the construction of towns and industries; by digging away sands in dune areas to acquire plains for bulb culture; by digging away almost all inland peat-bog areas for fuel; by dredging sands from the subsoil, resulting in the formation of deep water-filled basins, not unlike the basins once modelled by the inland-ice. All these human activities have changed the aspect of this country to such an extent that it is extremely difficult to perceive how the natural geological situation was, such a short time ago.

As shown in this paper a balance between sedimentation and subsidence existed during the palaeogeographic evolution of The Netherlands since more than one million years. Since that time the coast-line of interglacial episodes had a similar configuration as the present one. Only when the delicate balance was broken, for example after remodelling of the landscape by inland-ice during the Saalian, a temporary shift of coast-line further eastward has been observed. It should be realized that the succesful attempts of man to keep the sea out of this country may eventually result in a disturbance in the mechanism of equilibrium, which ultimately is responsible for the existence of this country.

EXPLANATORY NOTES

a. Stratigraphy, climate, absolute dating

With regard to the lithostratigraphic terminology used in the following notes reference is made to van der Heide and Zagwijn (1967) and fig. 5. See also Zonneveld (1958).

The climatic curve has been based on pollen-analytic data and other palaeoclimatic records available. Naturally this curve had to be composed from various sections. Concerning the Lower Pleistocene reference is made to Zagwijn (1963a, b) and Zagwijn (in press), the latter publication with particular reference to a warm interstadial phase in the Menapian. As to the absolute age of the base of the Quaternary see Zagwijn (in press). The curve of the Middle Pleistocene is still incomplete. The "Cromerian" is known to include at least three interglacials, and a number of interstadials (Zagwijn et al., 1971). However, it has appeared that the uppermost of these three interglacials in the Southern Netherlands may be correlative with the Pastonian of East Anglia. This would mean that beds dating from the younger Cromerian interglacial known in that area, have not been found to date in The Netherlands. For this reason the part of the curve reflecting the climatic change in the upper part of the "Cromerian complex" has been based on evidence from Eastern England (West and Wilson, 1966). The upper part of the entire curve has been based on Zagwijn (1973) for the Elsterian to Holsteinian, and on van der Hammen et al. (1967), and Zagwijn (1961) for the Eemian and younger.

Absolute datings namely radiocarbon datings are available from Weichselian (Vogel and Zagwijn, 1967) and Holocene beds (many datings, e.g. Jelgersma, 1961; Pons and Wiggers, 1959, 1960; Brand et al., 1965). Datings of older beds are mainly based on palaeomagnetic data (van Montfrans, 1971 a,b). Potassium-argon datings of volcanic rocks from the Eifel region have been tentatively used in dating some beds of the sequence in The Netherlands (Zagwijn, 1963b).

For Upper Palaeozoic axes of subsidence in the North Sea area see Heybroek (1974). Probably these axes have been active also during the Quaternary and they may have determined the position of the coastline during the last million years.

Names of areas, localities, rivers and borings quoted in the text will be found in fig. 6.

b. The maps (see enclosure).

1. *Reuverian B*

- Marine deposits: so-called Kallo Beds or Upper Scaldisian of The Netherlands – now foraminiferal subzone FA2 (Doppert, in prep.).
- Coast-line: Zagwijn, 1963b, van Voorthuysen, 1954, with adaptions among others for N. Belgium and the area east of Deventer. Also Zonneveld, 1958.
- Intertidal and brackish deposits: western part based on pollenanalytic data (Zagwijn, 1959); eastern part: Florschütz (Wychen), 1950; unpublished pollen-analytic data (e.g. boring Kloosterbos).
- Deposits of River Rhine: Kieseloölite Formation, upper part (Reuver Clay, Schinveld sands p.p.), Zagwijn, 1960, 1963b, also Zonneveld, 1947, Ahorner, 1962. Later erosion omitted.
- Deposits of North German rivers: Upper part of Scheemda Formation (considered part of Harderwijk Formation by Zonneveld, 1958). Based on pollen-analytic and heavy mineral data, mainly from eastern Groningen and central and S.E. Drenthe (unpublished).

Fig. 6
Geographic names and locations of borings quoted in the text.

2. *Middle Tiglian (C3)*
- Marine deposits: upper part of marine "Icenian" (= upper part of foraminiferal subzone FAl (D o p p e r t in prep.) = mollusc zone Moll A (S p a i n k, in prep.).
- Coast-line: Z a g w i j n, 1963 a,b.
- River Meuse: "Jülicher Schichten", Noorbeek-Simpelveld-Terrace deposits, reconstructed according to data of B r u e r e n, 1945; B r e d d i n, 1955; A h o r n e r, 1962; Q u i t z o w, 1956; Z o n n e v e l d, 1955; Q u i t z o w and Z o n n e v e l d, 1956.
- River Rhine: Z a g w i j n, 1963b. Comprises lower part of Tegelen Formation and part of "Ältere Hauptterrasse" (below "Tegelen Ton"). Data from Z o n n e v e l d, 1947, 1958; A h o r n e r, 1962; Z a g w i j n, 1960, 1963a, 1967.
- Brackish deposits: according to unpublished pollen-analytic data.
- North German rivers: Zuidlaren Formation (formerly part of Harderwijk Formation, Z o n n e v e l d, 1958). Pollen-analytic data: Z a g w i j n, 1963a, t e r W e e, 1966; unpublished (locality Zuidlaren). Heavy minerals M a a r l e v e l d, 1952, 1956; Z a n d s t r a, 1959, 1971 and oral comm.

3. *Upper Tiglian* (C5)
- Coast line: largely conjectural, as data in the area covered by the present North Sea are still very scarce. On land marine beds are completely absent.The alleged presence of *Macoma balthica* in boring Schoorl (T e s c h, 1912; H e e r i n g, 1940) has been taken as proof for the presence of "Icenian" beds of younger age as found elsewhere (Z o n n e v e l d, 1958; Z a g w i j n, 1963b). However, as shown by S p a i n k and N o r t o n (1967) the marine beds in this boring do not contain *M. balthica,* but *M. praetenuis*, and there is no reason to regard these beds of younger age than that of the other "Icenian" beds in The Netherlands. Unpublished pollen-analytic investigations have shown that the marine beds of boring Schoorl date from pollen zone TC4c and older and therefore are of similar age as the greater part of the marine lower Pleistocene deposits in this country (Z a g w i j n, 1963, a,b). In boring Schoorl (19A/21) the pollen analyses of non-marine beds overlying the marine deposits indicate also TC4c.
  In a clay bed near Halsteren, which by means of pollen analysis may be assigned to pollen zone TC5, Chenopodiaceae are frequent; furthermore some foraminifera have been found. This may indicate that the coast-line was not far away from this locality. However, localities further north do not show these features. The assumed shape of the coast-line is in accordance with these observations.
- River Meuse and River Rhine: the pattern in area outside the presence of marine lower Pleistocene beds is identical with the pattern in map 2. Elsewhere the presence of Tegelen Clay (dating from pollen zone TC4c to TC6) is shown (see also Z a g w i j n, 1963a).
- North German rivers: lowermost part of Harderwijk Formation, which according to pollen-analytic data from borings in Friesland and Noord-Holland is of similar age (pollen zones TC4c – TC6) (Z a g w i j n, in press; Z a g w i j n 1963a). Borings: Schoorl 19A/21; Scharwoude 19E/84; Diemerbrug 25G/132; Uitdam 25F/55; Eemnes 26D/5. In several places the coarse grained sands of the basal part of the Harderwijk Formation alternate with Tegelen Clay.

4. *Waalian interglacial*
- Coast-line: true marine beds of this age are still unknown. However, the presence of Chenopodiaceae and foraminifera in beds of this age in some localities, indicates that the coast-line may have been not far away (Dordrecht (38C/384), North Sea borings in blocks P5 and P9). The assumed course of the coast-line is in accordance with these observations.
- River Meuse and other southern rivers: deposits of this provenance are frequently found in the Central Graben area and less frequently in the Venlo Graben. They belong tot the Kedichem Formation (Z o n n e v e l d, 1958; Z a g w i j n, 1960, 1963a).
- River Rhine: beds of Kedichem Formation of Waalian age and occurring in an east-west running zone of the Central Netherlands contain heavy mineral assemblages characteristic for deposits of the River Rhine (D o p p e r t & Z o n n e v e l d, 1956; Z a g w i j n, 1963b). The pattern on German territory is hypothetic and is based on the distribution pattern further downstream (Z a g w i j n, 1963a).
- North German rivers: Upper part of Harderwijk Formation, with gravel assemblage rich in feldspar (type HOkv – Z a n d s t r a, 1959; also M a a r l e v e l d, 1952, 1956) dated by means of pollen analysis as Waalian in borings Harderwijk (unpublished). See also Crommelin, 1953. This part of the Harderwijk Formation has not been found in the region N.E. of Appelscha. As to the southern limit of its occurrence, it may be noted that beds of the Harderwijk Formation with beds of the Kedichem Formation have been found interfingering in the area between Gorkum and Utrecht (J e l g e r s m a & Z a n d s t r a, 1970).

5. *Upper part of "Cromerian complex"* (fig. 7)
- Age: As shown by Z a g w i j n et al. (1971) the lower part of the Middle Pleistocene of The Netherlands, which used to be considered of Cromerian interglacial age (e.g. Z a g w i j n and Z o n n e v e l d 1956) is in fact a complex of at least 3 interglacials which alternate with glacials. The two lowermost of these interglacials correlate with the interglacials of Osterholz (Osterholzian) in Germany and of Ølgod and Harreskov (Harreskovian) in Denmark respectively. In beds of the Urk Formation of the Northern Netherlands which definitely postdate these two interglacials, indications have been found for the

Fig. 7
Locations with Upper Cromerian beds, investigated by means of pollen analysis.
(Brouwer 1948; de Ridder and Zagwijn 1962; Bisschops 1973; unpubl.)
Encircled dots: marine.

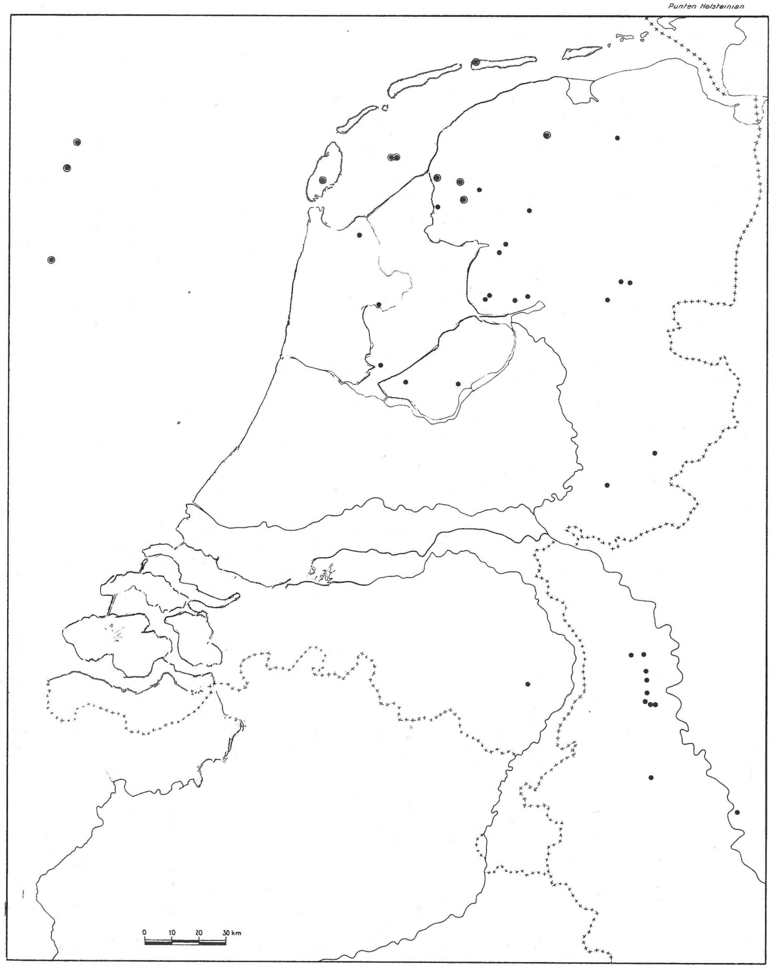

Fig. 8
Locations with Holsteinian beds, investigated by means of pollen analysis.
(Kaiser and Schütrumpf 1960; Kempf 1966; Zagwijn 1973; ter Wee 1974; unpubl.).
Encircled dots: marine.

existence of at least one more interglacial of pre-Elsterian age.

More recent investigations have revealed that in the Central Graben area of the Southern Netherlands the interglacial beds, present in the Rosmalen heavy mineral zone in the lower part of the Veghel Formation have to be older than Holsteinian (B i s s c h o p s 1973). Previously a Holsteinian age has been assumed for these beds by de R i d d e r and Z a g w i j n, 1962. These beds definitely post-date beds of the Sterksel Formation, which comprise the two lower interglacials of the "Cromerian complex". Therefore they should presently be placed in the upper part of the "Cromerian complex". Comparison of the two pollen diagrams available (Rosmalen – d e R i d d e r & Z a g w i j n, l.c.; Het Zwinkel – B i s s c h o p s, l.c.) with unpublished pollen diagrams from the Pastonian interglacial of East Anglia (W e s t – pers.comm.) has shown a close resemblance. On the other hand the pollen diagrams of the younger Cromerian interglacial (sensu typico) of East Anglia (which is also of pre-Holsteinian age) are different. If correlation of the Rosmalen interglacial with the Pastonian is correct, then it may be assumed, that in the upper part of the so-called "Cromerian complex" of The Netherlands two separate interglacials may be present, correlative with the Pastonian and the Cromerian (sensu typico) respectively. In this connection it may be interesting, that the pollen-diagrams available from the upper part of the "Cromerian complex" reveal an interglacial vegetational succession in the Northern Netherlands which is different from that observed in the Rosmalen zone of the Southern Netherlands. In the palaeogeographic reconstruction of map 5 no attempt has been made to separate these assumed two interglacials. Therefore this reconstruction probably pictures a composite situation.

Coast-line: In the Northern Netherlands interglacial marine beds are known in the subsurface at depths of 50 to 60 metres (e.g. Noordbergum). These beds are intercalated in the lower part of the augite bearing Urk Formation (Z o n n e v e l d, 1958). They have been considered to be of Holsteinian age (B r o u w e r, 1948; Z o n n e v e l d, 1958). However, more recently it has appeared, that these beds are overlain by deposits of the Peelo Formation, which are of Elsterian age (t e r W e e, 1974; Z a g w i j n, 1973). Therefore they belong to the upper part of the "Cromerian complex".

Similarly at Wassenaar in the Western Netherlands (boring 30G/34) marine beds have been found at a depth of about 40 – 49 m intercalated in the Urk Formation. The pollen-analytic data indicate that they should be placed in the upper part of the "Cromerian complex"

River Meuse: lower part of Veghel Formation (Rosmalen heavy mineral zone; Veghel A Formation) according to Z o n n e v e l d (1947, 1958); d e R i d d e r and Z a g w i j n (1962) and v a n d e n T o o r n (1967).

River Rhine: lower part of Urk Formation, heavy mineral zone rich in augite (= Urk Formation and greater part of Vianen Formation of Z o n n e v e l d, 1958). These beds underly the beds of the Peelo Formation in the Northern Netherlands. (Z a g w i j n, 1973; t e r W e e, 1974; R u e g g, in the press; Z a n d s t r a, in the press). In the coastal area of the Western Netherlands between Wassenaar and Velsen the base of the Urk Formation is about 60 – 70 metres below sea level (unpublished). Pollen analyses have shown (e.g. Kennemerduinen 25A/822; Velsen 25A/231) that the Urk beds here may be included in the upper part of the "Cromerian complex". In the lower Rhine district the approximate pattern of the "Mittlere Mittelterrasse" has been assumed to represent beds of this age (Q u i t z o w, 1959).

6. *Holsteinian interglacial* (fig. 8)

- Coast-line: although the greater part of the marine deposits previously included in the Holsteinian in the Northern Netherlands have appeared to be of pre-Elsterian age, a number of brackish and marine beds of actual Holsteinian age are presently known to occur also in this area. Marine deposits overlying so-called "potklei" (=pottery clay) of Elsterian age occur on the island of Ameland and probably underly the greater part of the Wadden Sea. Some other localities where marine influence in beds of Holsteinian age is evident are Den Burg and Nijland (Z a g w i j n, 1973). Furthermore, at Noordbergum in a restricted area north of the lake of Bergum marine beds with *Ostrea* and *Cardium* are present at a depth of about 20 m (boring 6D/49). They underly Saalian till and overly thick deposits of "potklei" of the Peelo Formation which is present in a north-south running gully. Pollen analysis has shown their Holsteinian age.
- River Meuse: part of Veghel Formation (Veghel B, according to v a n d e n T o o r n, 1967) on the basis of an unpublished pollen diagram of a clay deposit found in the subsurface of Helenaveen.
- River Rhine: Lower Rhine district of Germany – Krefeld and Kempen beds of Holsteinian age (K a i s e r & S c h ü t r u m p f, 1960; K e m p f, 1966) and other beds (v o n d e r B r e l i e et al. 1959).
- Eastern Gelderland: clay beds (Neede Clay) which have been previously attributed to the Eemian interglacial by v a n R e e s V e l l i n g a and d e R i d d e r, 1973, fig. 12. However, these beds are of Holsteinian age (e.g. boring Kloosterbos) with the exception of clay beds found in the subsurface close to the river IJssel, which are of Eemian age.
- Northern Netherlands: upper part of Urk Formation. Boundary according to Z a g w i j n (1973).
- Western and Central Netherlands: beds of Holsteinian age are known from the IJsselmeer area, from a few localities in the Veluwe area and from Hoorn. They are as yet unknown west of a line running approximately from Utrecht towards Hoorn. Beds of Urk Formation in that

area have appeared to belong to the upper part of the "Cromerian complex.'

7. and 8. *Saalian glacial*

- Pattern of ice-pushed ridges mainly according to M a a r l e v e l d (1953); Z o n n e v e l d (1958) and T e r W e e (1962).
- Pattern of glacial basins mainly according to J e l g e r s m a (in prep.).
- Pattern of fluvioglacial outwash (sandr plains) mainly according to M a a r l e v e l d (1955).
- In the subsurface in the Western Netherlands between the coast and Utrecht the top of the Pleistocene beds shows a plainlike morphology, which has been described as a burried cover-sand plateau (P o n s and B e n n e m a, 1958).
  Z o n n e v e l d (1958) has assumed that in this area fluviatile beds of the Kreftenheye Formation (postdating the Saalian glaciation) underly the plateau. Further to the north, however, Eemian and Weichselian beds showing a quite different facies are found at deeper levels as infill of glacial tongue basins. It is very difficult to understand how these beds could be of the same age as those underlying the plateau. A more comprehensible picture of events would be obtained by assuming, that the beds underlying the plateau may be older than the Eemian and Weichselian beds filling the glacial basins further to the North. Moreover, the beds underlying the plateau have a heavy mineral assemblage which is different from true Kreftenheye deposits further south, e.g. near Rotterdam, as the beds underlying the plateau are poor in augite. The heavy mineral assemblage resembles that of fluvio-glacial deposits of the Central Netherlands. Scandinavian pebbles have been found (J.D. d e J o n g, int. report), but are scarce. At one locality an intercalated clay-bed (boring Leimuiden 31A/94, depth about 30 m) has appeared to contain a reworked pollen assemblage characteristic of glacial and lacustroglacial beds.
  In constructing map 7, the assumption has been made that the plateaulike feature of the top of the Pleistocene beds found in the subsurface west of Utrecht represents an outwash-plain dating from the maximum extent of the inland-ice during the Saalian.
- River Meuse and River Rhine:
  Map 7: courses assumed in front and south of inland-ice. The River Rhine is known to have flown at that time through the Niers-valley (Q u i t z o w and Z o n n e v e l d, 1956; T h o m é 1959) and further towards the west.
  Map 8: The River Rhine had its course due north as demonstrated by v a n d e M e e n e and Z a g w i j n (in prep.). For the pattern in the IJsselmeer area reference is also made to W i g g e r s (1955), Z o n n e v e l d (1958) and t e r W e e (1963), with modifications.
  The Hunze-valley has been assumed to represent a valley eroded out by the River Ems (see also R o e l e v e l d, 1972).

9. *Eemian interglacial*

- Coast-line: according to Burck in P a n n e k o e k (1956), modifications by t e r W e e (1974) and R o e l e v e l d (1972). S.W. Netherlands mainly according to Z o n n e v e l d (1958). Coast-line Schouwen according to v a n R u m m e l e n (1970).
- River Meuse and Rhine: course of Rhine due north through IJsselvalley according to v a n d e M e e n e and Z a g w i j n (in prep.).
- River Scheldt: Valley of Gendt, see d e M o o r et al., 1969; v a n R u m m e l e n, 1965, 1970, 1972.
- Peat bogs: v a n d e n T o o r n (1967 – Asten Formation of Peel area); t e r W e e 1966; Z a g w i j n (in press), and unpublished data.

10. *Weichselian glacial*

- Depth contours: according to P o n s et al., 1963.
- River Meuse and Rhine; Kreftenheye Formation. River Rhine broke through ice-pushed ridge of Montferland-Reichswald during the Weichselian pleniglacial (v a n d e M e e n e and Z a g w i j n, in prep.).

11. *Holocene 5.000 B.C.*

- Mainly after P o n s et al., 1963, with additions and modifications.

12. *Holocene 2.300 B.C.*

- This map gives the situation during the Calais IVa transgression phase.
- Groningen: R o e l e v e l d (1974).
- Friesland: t e r W e e (1974).
- Coastal barriers: J e l g e r s m a et al., 1970.
- Northern part of North Holland: P o n s et al., 1963 – encl. 5 and 6; E n t e, Z a g w i j n, M o o k, in press.
- River-clay area: V e r b r a e c k, 1970; d e J o n g, 1972.
- Area of IJ-estuary: Z a g w i j n, 1971.
- South-western Netherlands: P o n s et al., 1963 – encl. 5 with modifications; H a g e m a n, in prep.
  It should be remarked that present knowledge on the age of various Calais deposits in the SW Netherlands and North Holland has resulted in a correlation different from that used by P o n s et al. (1963).
  Furthermore the relation between the tidal inlets and the pattern of the coastal barriers is understood at present in a different way (J e l g e r s m a et al., 1970; E n t e et al., in press).

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Enclosure
Palaeogeographic maps of The Netherlands during the Upper Tertiary and Quaternary